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OBSCURATION DUE TO DUST OF A LASER BEAM IN A GUN FIRING ENVIRONMENT

by Gerald Goble

PRELIMINARY SURVEY REPORT
OCTOBER 1975

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A review of the literature addressing the present state-of-the-art research on obscuration due to gun blast is presented. The dynamics of the dust cloud, composition of the dust, theoretical approaches to scattering of laser energy and experimental obscuration measurements are discussed. Papers with significant results on obscuration are presented, and the requirements for further studies are outlined. A bibliography on related gun blast and muzzle brakes studies is included.

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I. INTRODUCTION

The purpose of this report is to document the depth of information available on obscuration due to dust as it pertains to a tank firing environment. As the general complexity of military operations increases, the effect of environmental factors increases in proportion. The fact that dust is often raised and obscures the sight of military personnel in an operation is well documented. However, with the advent of laser equipment into the battlefield a serious question is raised on equipment effectiveness under dusty conditions. Dust is raised on the battlefield by exploding shells close to the ground, vehicular as well as foot traffic, and gun blast. In this report the dust raised by gun blast is the source investigated for the specific case of a laser beam directed through the gun blast environment.

A survey was conducted on all DOD holdings on obscuration due to dust, using the key words, Mie calculation obscuration, gun blast, blast suppressors, muzzle brakes, absorption spectra of clay, and laser scattering due to dust. The results of that survey are given with the major reports discussed in detail. This survey does not cover the work done on blast and flash suppressors but is restricted only to obscuration due to dust and dust suppressors.

A summary of the depth of material on gun blast was made and a partial reference list is given in Appendix A. The list is provided as an aid and the articles have not been abstracted. The articles listed are some of the major articles chosen to cover the subject as completely as possible.

The overall depth of DOD knowledge in the obscuration due to dust is determined and the additional information required for assessment of effectiveness of modern weapon systems is detailed.

The studies on obscuration due to gun blast cover the areas of description of the dust cloud mechanism, development of a scaling law for obscuration due to gun blast, particle size measurements using Mie theory, and mechanical muzzle device development to reduce the obscuration effect of gun blast.

The requirements for further investigations on obscuration are given with the emphasis on experimental setup, environmental factors and related studies that would complete the data base in order to fully determine the effect of obscuration due to dust.

II. HISTORICAL SURVEY

The earliest comprehensive survey(1) on obscuration due to dust was conducted in 1941-1945. This survey was conducted by General Electric Company, Princeton University, and the California Institute of Technology. The GE report describes an experimental effort using a sand table, air blast apparatus, and photographic equipment. The blast mechanism and the various stages involved as the blast raises dust were defined by use of photographs of the dust table blasts.

The generation of dust was broken down into five components. The relative importance of the five components was not given. These five components are described:

a. From the time of ignition a pressure wave propagates spherically outward from an origin located in the breech. The geometry of this wave is subject to the geometry of the barrel and surroundings and also the effect of the emergent gases beginning to be emitted from the barrel, making its actual shape not perfectly spherical. As the pressure wave propagates spherically outward and passes a given point on the ground, pressure will first be felt downward as the front part of the wave passes and upward as the trailing part of the wave passes. This phenomenon can be shown by application of Huggen's principle. The vertical component of the force on the ground along with frictional force of the air bubble expansion causes dust to be raised as the bubble or sphere collapses.

b. After the initial dust is raised the continuing gas flow from the muzzle carries the center of the initial cloud downstream. The remaining dust is in the shape of two vertical columns, one on each side of the muzzle.

c. As the emergent shell and gas move forward, a ring vortex is formed and proceeds downstream. The vortex ring grows as it proceeds and intersects the ground at the approximate time that shell pierces the emerging "spherical" pressure wave. The impact of this vortex ring and the resulting frictional force of the air on the ground raises additional dust.

d. When the barrel is close to the ground or tilted downward, the emergent stream of gas will partially deflect off of the ground causing dust to be raised downstream of the vortex. The vortex will then carry this dust to larger heights.

e. When the vortex has grown to the point where approximately a third of it has reflected or impacted on the ground, it will subdivide by the process of vortex shedding into vertical straight vortices or tornado like air movements. These vortices are on each side of the gas stream and move in a circular path (radius approximately the distance at which vortex hits the ground) away from the stream. The amount of dust raised by these vortices is small but they serve as a mechanism for spreading the dust cloud.

f. Finally, dust raised by friction can be carried further by winds so that the height of the cloud increases significantly down wind. The amount of dust raised by the wind is dependent on the wind speed and direction.

The sand table tests assume an environment in which the gun is fired over perfectly dry soil so that a maximum amount of dust can be created. Further, the table and sand particle sizes were scaled relative to the actual size of a 75mm gun.

A further work by J. J. Slade[2] documents the gun blast mechanism and the raising of dust by gun blast by relating it to 75mm test firings. In this report a scaling law is given for determining the amount of "dustiness" created by gun blast.

$$D = \frac{W^{3/2}}{h^2} k \qquad (1)$$

In the above formula, D is the amount of dust, W is the weight of the propellant charge, h is the height of the muzzle from the ground, and k is equal to one with units as to make D dimensionless. If gun firings with the same propellant are compared, the weight of the propellant can be replaced with the caliber of the round. A 1949 survey[3] further documents work done in this area and combines the results of the previous works[1,2] and others. Although the 75mm test firings are compared[3] with firings of the British 6 pr on the Centaur, this represents only one data point in confirming the scaling law. However, the scaling law can be used to determine the approximate size of the dust cloud for firings of a 105mm gun on the M60 tank (see Table 1).

The scaling law was determined be measuring photographs of the 75mm firings. Calculated values[4,5] for a 105mm gun assuming the same propellant are given and plotted in the diagram in Figure 2. The propellant charge has changed since the 1949 75mm firings and a comparison of an actual firing has not been made.

The effect of dust particle size in a water-smoke model was done[6] using a Mie calculation method. Wavelengths of 0.53, 1.06, and 10.6 m were considered in the model. Refraction indices for commonly occuring clays are given and the effect of dust (Aberdeen dust) on the model is shown. Spectroscopic and light scattering techniques are used to identify muzzle gas and aerosol components. Concentrations of ammonia gas from the muzzle emission producing extinction in the 10.6μm spectral region are identified. The obscuration arising from gun muzzle emission and clay are distinguished and the evolution of each aerosol is followed in terms of particle size and number density.

TABLE I

SCALING LAWS FOR THE SIZE OF THE DUST CLOUD
FOR A TANK GUN FIRING (3,4,5)

DIMENSION	LAW	75mm TEST*	105mm **
Diameter of the vortex when intersecting the ground	$d_1 \doteq 2h$	4.4M	4.6M
Distance in frount when vortex intersects the ground	$d_2 \doteq W \times 0.063$	4.7M	6.6M
Width of the dust cloud at the largest point	$d_3 \doteq D \times 20.82$	7.6M	12.2M
Length of the dust cloud at the largest point	$d_4 \doteq D \times 73.97$	27.3M	48.4M

* The 75mm test values were measured from photographs.
** Predicted values for the 105 mm were made assuming the same type charge was used in both of the shells and only the weight of the material changed.

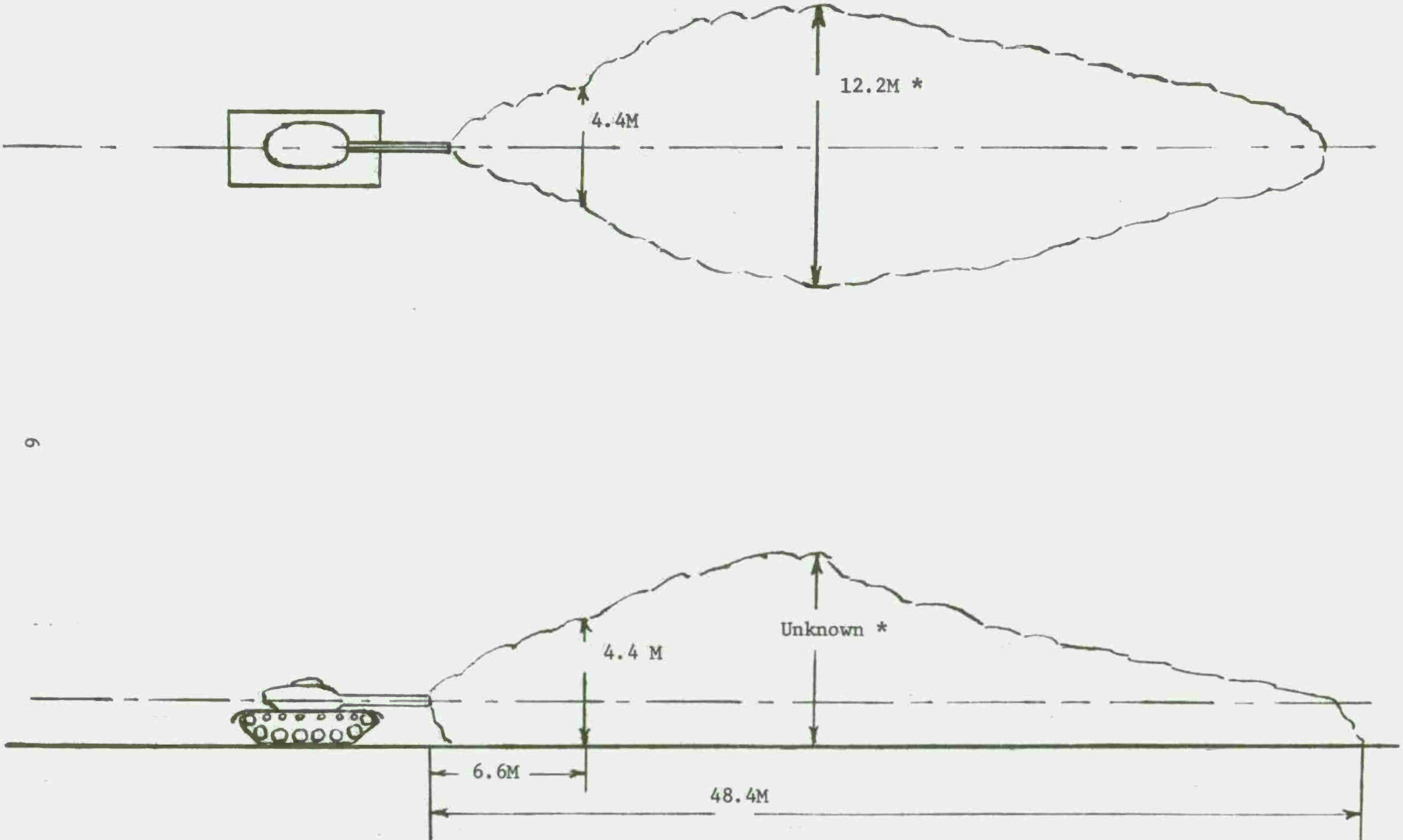


FIGURE 1. PREDICTED SIZE OF THE DUST CLOUD FOR A 105mm GUN USING SCALING LAWS
* These values depend on local environmental conditions.
** The time is approximately 4 sec. after firing.

The results indicate particle size 1.4 to 1.0μm in diameter for the first two seconds. Particle diameter at three seconds is probably near 5μm. The rising dust cloud causes an increasing number density at the muzzle level during the period from three to six seconds. This report indicates a factor of three dependent on geographical location for obscuration due to dust.

A sample clay (Aberdeen clay) was measured[6] and the relative weights of the components are given in Table 2 along with comparison measurements[12] of other interesting locations. The values in this table are for single measurements and there has been no attempt to find the most probable material encountered. In Tschebotarioff's book[7] it is shown that as soil is put through smaller and smaller sieves, the proportion of clay becomes higher while the proportion of sand and organic products becomes lower. At 1μm the proportions of silicate clay is greater than 80%. Since the sample soil measured at Aberdeen[6] was 35% montrillonite, 20% kaolinite, and 20% illite (principally clay materials), the action of raising dust by gun blast is as a sieve, separating out particles down to .5μm in diameter. It would therefore be reasonable to say that the proportions measured in the Aberdeen test would be a good measure of dust at most locations, which would be clay. An exception would be the reduction of water in the soil such as desert locations, which will cause H and OH bonds to break giving a larger fraction of the smaller clay molecules. The Mie calculations of clay given in Reference 6 are therefore significant in the analysis of obscuration due to dust. Since the report[6] is difficult to obtain, their references are given as references 8 - 17, along with some additional references on the absorption spectra of clay.

A BRL Report[8] gave the results of test firings at Aberden and Ft. Irwin. A 0.6328μm laser located 100 feet in front of the M60 A1 tank tube muzzle was directed toward a detector located behind the tank. A 20 ft x 40 ft plywood cover was spiked to the ground in front of the tank in the Ft. Irwin test to reduce the amount of dust.

Data tables are given on the percent of spectral transmittance for several test firings at both locations. The results of this test indicate that there was less attenuation for the Ft. Irwin test which lasted longer. Because of the use of the plywood cover, however, as a measure of obscuration for a desert location, the test at Ft. Irwin is questionable.

The majority of the work in the area of obscuration due to gun blast has been done in connection with development of gun blast and flash suppressors (see Appendix). Some studies[19,20] have been undertaken to look at the obscuration problem comprehensively but are for the most part not adequate in terms of modern laser technology. The studies on blast suppressors indicate that, in general, the obscuration due to dust can be reduced significantly (up to 70%) by the use of a muzzle device. The price that must be paid for use of such a device is increased pressure in the gun crew area. No attempts have been made to coordinate these efforts with modern laser technology.

TABLE 3

CLASSIFICATION OF COMPARATIVE SOIL BY WEIGHT (6,7)

MINERAL	CHEMICAL	ABERDEEN**	MOJAVE***	WEST GERMANY***	SINAI***
Montmorillonite	$(0.5Ca,Na)_{0.7}(Al,Mh,Fe)_4 (SiAl)_8 O_{20}(OH)_4$	35%	25%	45%	25%
Kaolinite	$Al_4Si_4O_{10}(OH)_8$	20%	20%	19%	17%
Illite	$K_{1-1.5}Al_4Si_{7-6.5}Al_{1-1.5}O_{20}(OH)_4$	20%	20%	10%	20%
Calcite	$CaCO_3$	15%	15%	20%	20%
Quartz	SiO_2	5%	5%	*	5%
Hematite	Fe_2O_3	*	5%	5%	8%
Corundum	Al_2O_3	*	5%	*	2%
Thenardite	$NaSO_4$	*	2%	*	1%
Halite	NaCl	*	2%	*	1%
Other	MnO, TiO, CaO, MgO, K_2O $Na_2O, P_2O_5, \ldots$	5%	1%	1%	1%

*Not Measured, see "Other" category.

**Reprinted from Ref 11, Values taken from single measured sample.

***Estimated from percentages of soil composition.

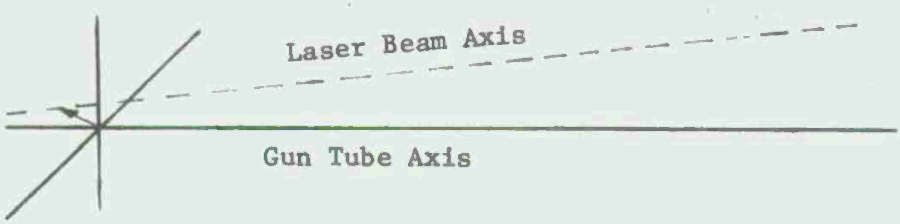
III. REQUIREMENTS OF FURTHER STUDIES

The previous studies on obscuration were based on the definition of obscuration as the ability of the observer to see the target.

The problem of laser obscuration is considerably better defined since the power of the transmitted light and the sensitivity of the optical sensor can be measured. Further, the frequency of a laser transmitter sensor system is not restricted to the visible region. With a laser system if the beam is 50% obscure then the power received at the sensor is half of that normally received at the sensor.

The problem of obscuration of a laser beam in a dust cloud created by a tank firing is more complex than the definition given above. To determine the effect of the dust cloud on a beam from a beam projector located on the turret as close as possible to the axis of the gun tube several items must be known:

1. The geometry of where the observation occurred relative to the gun tube axis.



2. Input versus output power.

3. An evaluation of environmental factors.

a. Amount of dust that can be raised is dependent on the time of year, compactness of the soil, moisture content of the soil, distribution of particle size in the soil and many other factors.

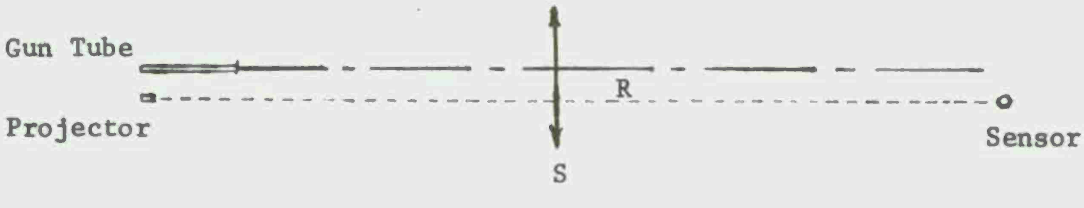
b. Given the values in a, then what is the degradation due to battle.

<u>Rationale and Recommendations of Important Factors in Obscuration Measurement and Determination</u>

Each of the important factors in measurement and determination of obscuration due to gun blast is discussed below, with recommendations for the scope of the study needed to adequately define the problem area.

Geometry Factors - From the work described in section II a beam projector located as near as possible to the gun tube axis would see the maximum amount of changes in the dust cloud.

Consider the following experimental set up. A beam projector is set up at a distance R from the gun tube, with the axis of the tube and the axis of the projector parallel.



The distance S is the diameter of the emerging Vortex as it intersects the ground.

A measurement of the change in the beam power received at the sensor should be relatively sensitive to the position of the beam. This can be determined intuitively by watching a smoke ring emerge from a persons mouth and noting the differing density of the smoke at the center and in the ring. Further, the gases emerging from the barrel have an angular component to their motion. These factors indicate that several positions relative to the axis should be measured to determine the effect of the projector-gun axis geometry. The bounds on the perpendicular distance of the beam axis from the tube axis is $R \ll S$. The BRL report[18] recommends that the size of R be two feet offset from the muzzle parallel to the direction of the muzzle, and the muzzle directed horizontal. It would be better to have several values of R measured at the same time.

Laser Beam - The degradation of the beam power by the dust cloud must be separated from the amount of degradation of the beam due to the rapid motion of the air. Firing over dusty and non-dusty environments gives a measure of this effect. This practice has been followed in most tests described in Section II and has been included for completeness. Several wavelengths should be measured at the same time with 1.06 m included since it is proposed for several systems.

Environmental Factors - The measurement of environmental factors has been only cursorily accomplished in most of the tests. The objective of environmental measurements in the tests should be to develop an environmental scaling law from which predictions can be made on environmental contribution to obscuration. The parameters involved need to be defined as well as rated as to their relative importance. The historical effect of the test on these parameters need to be considered in order to estimate the obscuration as a battle progresses. A few of the environmental parameters are:

a. Compactness of soil in front of the gun tube before and after test.

b. Distribution of size and mass of particles in the soil before and after the test.

c. Distribution of the size and mass of the particles raised as dust.

d. Average rainfall, moisture and temperature of the soil.

e. Wind speed, air temperature and humidity.

Effort should be directed to calculating the data taken with the standard tabulated climatology data, and obscuration measurements should be taken without altering the environmental conditions.

Intelligence Survey - Once the critical environmental parameters are defined for obscuration due to dust an intelligence survey for the most probable battle sites should be requested. The survey should determine the environmental parameters at the given battlefield sites at several times during the year. Comparing the environmental parameters for obscuration and the environmental parameters for battlefield sites gives a probable obscuration for those sites and thereby a measure of weapon effectiveness.

Beam Projector Usage - The projected use of a laser beam projector on a tank turret should be investigated. The tactical probability of a tank firing from behind a soil bunker or from the top of a hill should be considered, since the distance from the height of the muzzle is an important factor. Such information would also provide an evaluation of the weapon in battle.

Simulating Obscuration - Simulation of the effect of obscuration due to dust should be done for single as well as multiple firings. Further, the effects of environmental intelligence surveys, and tactical weapon usage should be included to get an evaluation of weapon effectiveness under battlefield conditions.

Muzzle Devices - An additional evaluation should be made as to the acceptability of using muzzle brakes for operations under dusty conditions. The tradeoff that arises is the acceptability of elimination of dust by deflection of the blast versus the increased back pressure in the gun crew area. In particular for desert operations, it may be more preferred to use a blast deflector mechanism than to expand more development over longer time designing laser weapons systems for these particular adverse donditions.

Blast Scaling Law - Rounds of different weight propellant should be fired at several heights of the muzzle to provide additional data in confirming the scaling law. Measurements of the firing of different weapons would also be useful in expanding the data base available on obscuration.

APPENDIX A

Partial Bibliography for State-of-the-Art
Literature Search on Gun Blast and Muzzle Break Technology

Listed by Author

1. Abbett, M., "Mach Disk in Underexpanded Exhaust Plumes," AIAA J., Vol. 9, No. 3, 1971.

2. Hennessy, Robert T., Borden, Gail J., "Jet Blast Deflector (JBD) Operator Performance: Analysis and Recommendations," Human Factors Research Inc., Goleta, CA, TR-1763, May 1975.

3. Brode, H., "Point Source Explosion in Air," Rand Corporation RM-1824-AEC, December 1956, (AD 133 030).

4. Brode, H., "A Calculation of the Blast Wave from a Spherical Charge of TNT," Rand Corporation, RM-1965, August 1957. (AD 144 302).

5. Millikan, C., Secher, E., and Buhler, R., "A Study of Blast Deflectors, Final Report," National Defense Research Council, Report A-351, October 1945.

6. Carfagno, S., and Rudyi, O., "Relationship between Propellant Composition and Flash and Smoke Produced by Combustion Products (U)," Franklin Institute, Final Report F-A2132, December 1960, (AD 321 118). (Confidential).

7. Carfagno, S., "Handbook on Gun Flash (U)," Franklin Institute, November 1961. (AD 327 051). (Confidential).

8. Corner, J., "Theory of Interior Ballistics of Guns," John Wiley and Sons, New York, 1950.

9. Dear, V., and Smithies, F., "Tests of Muzzle Brakes for the Q.F. 6 PR., 7 cm. Gun," Gun Design Committee, A. C. 4162/GN. 260, June 1943.

10. Dodson, T. I., Miller, R. E., Knight, R. D., "MK 56 Structural Firing Aboard the USS Talbot (DEG-4), "Naval Surface Weapons Center, Dahlgren Lab, VA, NSWC/DL-TR-3201, Dec 1974, (AD No. B000812L).

11. Hill, J., and Draper, J., "Analytical Approximation for the Flow from a Nozzle into a Vacuum," J. Spacecraft, Vol. 3, No. 10, 1966.

12. Eddy, James R., "Check Test of Grapnel, Launcher-Propelled, XM1," APG-MT-4371, Nov 1973, Aberdeen Proving Ground, MD (AD Number: 915796L).

13. Engineering Design Handbook, Ballistic Series, "Interior Ballistics of Guns," AMCP 706-150 US Army Materiel Command, Feb 1965.

14. Engineering Design Handbook, Gun Series, "Muzzle Devices," AMCP 706-251, US Army Materiel Command, May 1968.

15. Engineering Design Handbook, "Spectral Characteristics of Muzzle Flash," AMCP 706-255, US Army Materiel Command, June 1967.

16. Fay, J., "The Physical Mechanism of Gun Flash," Midwest Research Institute, Progress Report 1, June 1954.

17. Frey, W. M., McJilton, W. N., Reichard, B. L., "Muzzle Deflection and Target Resolution ZU-23-2 Antiaircraft Gun," BRL-MR-2435, Jan 75 (AD B001871L).

18. Fluk, Harold, Goddis, Neil, "Jet Flow Analytical Mode with Application to the Viol Porous Platform," NAEG-ENG-7874, Naval Air Engineering Center, Philadelphia, PA, Engineering Dept (SI), 22 May 74, (AD 919498L).

19. Sibulkin, Gallaher, W., "Far-Field Approximation for a Nozzle Exhausting into a Vacuum," AIAA J., Vol 1, No. 6, 1963.

20. Gentil, M., "A Summary of the Studies of Muzzle Brakes," Memorial de L'Artillierie Francaise, Vol. XV, 1936.

21. Munch, N., MacKay, M., and Greengrove, R., "80mm Gun Blast Deflector Development," Power Generators, Inc., Report 1398, September 1955, (AD 836 751).

22. Skochko, L., and Greveris, H., "Silencers," Report R-1896, Frankford Arsenal, August 1968.

23. Hammer, E., "Muzzle Brakes, Volume I: History and Volume II: Theory," Franklin Institute, June 1949 (AD 111481).

24. Heiney, O., "Simplified Interior Ballistics of Closed Breech Guns," AFATL-TR-67-42, April 1967, (AD 822 447).

25. Hill, A. B., Jr., "LCM Delivery of M125 Line Demolition Charge," NCSL-229-75, Feb 1975, Naval Coastal Systems Lab, Panama City, FL, (AD B002304L).

26. Hodil, E., and Merrill, D., "Weapon Development, Multiple Flechette Weapon System Development Contract," Winchester-Western, October 1970.

27. Hunt, F., "Internal Ballistics," Philosophical Library, New York, 1951.

28. Irvine, J. H., "Gun Technology Bibliography for a State-of-the-Art Literature Search," NWC TP 5483, Naval Weapons Center, July 75.

29. Kazincky, L., "Theoretical Considerations in Regard to the Construction of Muzzle Brakes," Memorial de L'Artillerie Francaise, Vol. IX, 1930.

30. Leese, Grady, W., "Ground Wash Flow over Deflecting Walls, Report 1, Feasibility Study," AEWES-MISC-Paper-S-69-25-1. Army Engineer Waterways Exp. Station, Vicksburg, MI, Jun 69, (AD 731199).

31. Levin, S., "Concept and Feasibility Studies of Muzzle Brake Blast Suppression Devices for 105mm and 155mm Howitzers," Ordnance Engineering Assoc., Report P.N. 2070, Feb 1964, (AD 601 728).

32. Naval Air Test Center, Patuxent River, MD, "Evaluation of Prototype Wing-fold Liquid Spring Bellcrank," NAFC-FT-72R-74, 12 Sep 74, (AD 922774L).

33. US Navy Gun Blast Committee, "Survey of Research on Blast (U)," First Interim Report, 1946 (Confidential).

34. Oswatitsch, K., "Flow Research to Improve the Efficiency of Muzzle Brakes," Part I - "Tests on Baffle Surfaces with One-Dimensional Flow," German Air Research Report 6601, July 1943; Part II - "Efficiency Factor, Momentum Relation, Two-Dimensional Flow, and Flow with Covering," Research and Development, Army Ordnance, Report 1001, October 1944; Part III - "The Axial Symmetric Flow Problem, a Comparison of Tests of Muzzle Brakes Free of Reaction," Gottingen, March 1945.

35. Oswatitsch, K., "Intermediate Ballistics," Deutsche Luft and Raumfahrt FB 64-37, DVL Beright 358, December 1964.

36. Pai, S., "Fluid Dynamics of Jets," D. Van Nostrand, New York, 1954.

37. Quayle, P., "Spark Photography and its Application to Some Problems in Ballistics," Scientific Papers, Bureau of Standards, Vol. 20, No. 508, 1925.

38. Rateau, A., "The Theory of Muzzle Brakes," Memorial de L'Artillerie Francaise, Vol XI, 1932; Comptes Rendue, Vol. 168, 1919.

39. Reisler, R., Raley, R., and Lefevre, D., "Air Blast Measurements Recorded by Standard and Developmental Instrumentation," P.O.R. 4030, Operation Sailor Hat, NDA, July 1967, (AD 819 459).

40. Reynolds, G., "Muzzle Blast Pressure Measurements," Princeton University, Report PMR-21, April 1944.

41. Robinson, E., and Wilson, E., "Reduction of Smoke and Blast Obscuration Effect," National Defense Research Council, Report A-325, May 1945.

42. Slade, J. J., "Muzzle Blast: Its Characteristics, Effects, and Control," National Defense Research Council, Report A-391, March 1966.

43. Schlenker, G., "Theoretical Study of the Blast Field of Artillery with Muzzle Brakes," Rock Island Arsenal, Report 62-4257, December 1962.

44. Schlenker, G., "Contribution to the Analysis of Muzzle Brake Design," Report 62-1794, Rock Island Arsenal, May 1962.

45. Schmidt, E. M., "Muzzle Devices, A State-of-the-Art Survey, Vol I: Hardware Study," BRL Report MR 2276, Feb 1973, AD 909325.

46. Smith, F., "Model Experiments on Muzzle Brakes," Report 2/66, June 1966, Royal Armament Research and Development Establishment, (AD 487 121).

47. Smith, Sheldon D., "Study into the Operation Characteristics of a Recoilless Rifle Mounted on Helicopters. Vol. I - Experimental Investigation into the Effect of Suppressing Recoilless Rifle Blast Utilizing a Porous Diffuser and Deflection," LMSC-HREC-TR-D306785-1, Jul 1974, Lockheed Missiles and Space Co., Huntsville, AL, Huntsville Rsch and Engineering Center, (AD 783428).

48. Smith, F., "Model Experiments on Muzzle Brakes, Part III: Measurement of Pressure Distribution," Report 3/68, February 1968, Royal Armament Research and Development Establishment (AD 845 519).

49. Thorpe, C. J., "Trials and Development HMS Ark Royal Deck Cooling and Jet Blast Deflec Equipment," RAE-TR-72217, Mar 1973, Royal Aircraft Establishment, Farnborough (England), (AD 914698L).

50. Townsend, P., "Development of a Gas Gun to Investigate Obscuration Effects," WECOM Report 66-2381, Nov 66, (AD 804 815).

51. Vottis, P., "Digital Computer Simulation of the Interior Ballistic Process in Guns," WVT 6615, Watervliet Arsenal, Oct 65, (AD 805 248).

52. Westine, P., "Modeling the Blast Field Around Guns and Conceptual Design of a Model Gun Blast Facility," Report 02-2643-01, Sep 70, Southwest Research Institute, (AD 875 984).

53. Whitham, G., "On the Propagation of Shock Waves through Regions of Non-Uniform Area or Flow," Vol 4, 1958, J. Fluid Mech.

54. Young, H., "Smoke and Flash in Small Arms Ammunition, 1948-1955," Midwest Research Institute, 1954 (AD 88 537).

55. Zoltani, C. K., "Muzzle Devices: A State-of-the-Art Survey Vol II: Theoretical Approaches to Calculation of Muzzle Blast," BRL Report MR-2294, May 73, (AD 912523).

REFERENCES

1. E. Robinson and E. Wilson, "Reduction of Smoke and Blast Obscuration Effect," NDRC Report A-325, (National Defense Research Council, Wash., D.C., 1945).

2. J. J. Slade, "Muzzle Blast: Its Characteristics, Effects and Control," NDRC Report A-391, (National Defense Research Council, Wash., D. C., 1966).

3. E. Hammer, "Muzzle Brakes, Volume I: History and Volume II: Theory II," (Franklin Institute, Wash., D. C., 1949), (AD 111481).

4. E. M. Schmidt, "Muzzle Devices, A State-of-the-Art Survey Volume I: Hardware Study," BRL MR 22276, (Ballistics Research Laboratory, 1973), (AD 909325); C. K. Zontani, "Muzzle Devices, A State-of-the-Art Survey Volume II: Theoretical Approaches to the Calculation of Muzzle Blast," BRL MR 2294, (Ballistics Research Laboratory, 1973), (AD 912523).

5. "Development of a 105mm Gun Main Battle Tank," TIR 3-1-2J2, (US Army, Wash., D. C., 1959).

6. E. W. Stuebing, F. D. Verderame, R. W. Doherty, J. J. Pinto, E. A. Lucia, and SP4 G. Vinansky, "The Nature of Smoke and Dust Obscuration Due to Cannon Firing," (Pitman Dunn Laboratory, Frankford Arsenal, Philadelphia, 1975).

7. G. P. Tschebotarioff, "Soil Mechanics, Foundations and Earth Structures," (McGraw Hill Publishing Co., New York, 1951).

8. J. Heater, C. Ponlelandolfo, and J. M. McKeough, "Rarden 30mm Obscuration Measurements," (US Army, Frankford Arsenal, Philadelphia, 1975).

9. E. W. Stuebing, J. J. Pinto, and R. B. Gomez, "PGAUSS-LT: A Program for Computing Optical Properties of Single Scattering Aerosol Clouds of Homogeneous Particles," FA-TM-75019, (Pitman Dunn Laboratory, Frankford Arsenal, Philadelphia, 1975).

10. G. Hanel, "Computation of the Extinction of Visual Radiation by Atmospheric Aerosol Particles as a Function of Relative Humidity, Based on Measured Properties," Aerosol Sci. (1972).

11. K. Fischer, "Bestrimmung der Absorption von sichtbores Strahlung durch Aerosol partikeln," Beitr-Phy-Atm-43, pp 244 (1971).

12. L. J. Bellamy, "Infrared Spectra of Complex Molecules," (John Wiley & Sons, New York, 1958), 2nd Ed.

13. J. M. Hunt, M. P. Wisherd, and L. C. Bonham, Ana Chem, 25, pp 1159, (1953).

14. W. K. Keller and E. E. Picket, Am. Jor. Sci., 248, pp. 264 (1950).

15. W. D. Keller, J. H. Spotts, and D. L. Biggs, Am. Jor. Sci, 250, pp 453 (1952).

16. W. M. Tuddenham and R. J. P. Lyon, Ana. Chem. 31 pp. 377 (1959).

17. G. G. Gubareff, J. E. Janssen, and R. H. Torborg, "Thermal Radiation Properties Survey," (Honeywell Research Center, Minneapolis, Minn, 1960), 2nd Ed.

18. R. T. Gschwind and S. A. Dunbar, "Spectral Transmission Through a Tank Firing Environment," BRL IMR-78, (Ballistics Research Laboratory, 1973).

19. P. Townsend, "Development of a Gas Gun to Investigate Obscuration Effects," WECOM Report 66-3281, (U.S. Army Weapons Command, Rock Island, IL., 1966), (AD 804815).

20. W. M. Frey, W. N. McJilton, and B. L. Reichard, "Muzzle Deflection and Target Resolution ZU-23-2 Antiaircraft Gun," BRL MR-2435, (Ballistics Research Laboratory, 1975), (AD B001871L).

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